A Moving IR Point Target Detection Algorithm Based on Reverse Phase Feature of Neighborhood in Difference Between Neighbor Frame Images

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Abstract: An algorithm for detecting moving IR point target in complex background is proposed, which is based on the Reverse Phase Feature of Neighborhood (RPFN) of target in difference between neighbor frame images that two positions of the target in the difference image are near and the gray values of them are close to in absolute value but with inverse sign. Firstly, pairs of points with RPFN are detected in the difference image between neighbor frame images, with which a virtual vector graph is made, and then the moving point target can be detected by the vectors' sequence cumulated in vector graphs. In addition, a theorem for the convergence of detection of target contrail by this algorithm is given and proved so as to afford a solid guarantee for practical applications of the algorithm proposed in this paper. Finally, some simulation results with 1000 frames from 10 typical images in complex background show that moving point targets with SNR not lower than 1.5 can be detected effectively.

Key words: pattern recognition; target detection; point target; difference image; RPFN

基于邻帧差分近邻反相特征的红外运动点目标检测算法. 朱风云，秦世引. 中国航空学报(英文版)，2006, 19(3): 225-232.

摘　要：基于运动点目标在邻帧差分图像中所具有的近邻反相特征，即运动点目标的两个位置相邻近、灰度值一正一负，提出一种在复杂背景下,基于红外序列图像的运动点目标检测算法。本算法利用该特征在邻帧差分图像中检测反相点对，进而构造反相点对矢量图，最后依据累积反相点对矢量图中多矢量首位相接的连续性检测出运动的点目标。文中给出并证明应用本算法能以概率1 检测到运动点目标的收敛性定理。对典型复杂背景下 10 幅 1000 帧图像的仿真结果表明，当信噪比大于或等于 1.5 时，可以有效检测出运动点目标。

关键词：模式识别；目标检测；点目标；邻帧差分图；近邻反相特征

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Detecting IR point target in complex background is an important and basic problem in many fields, especially for military applications. It is a key technique for IR early-warning system, IR tracking system, IR image-guidance system, and so on. The study on this problem is valuable in theory and important to practical application[1].

The point target refers to the target with only one pixel in this paper. As for a target with only one pixel in complex background, the difficulty of detecting it is obvious, because there is no general feature, such as edge, shape or texture, which can be used in detection. So it is difficult to detect point targets even in sequence images, say nothing of detection in one frame image. How to detect a point target in clutter background with many kinds of noises is an issue in the field[1].

The initial work on detection for a moving

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target in IR image sequences is the idea of Track-Before-Detect (TBD)[2], and the method is still in the course of improvement recently[3]. Although it is a global optimal result, it is impossible to be used in practice because of long computation time since the entire 3-D space must be searched for all possible trajectories for each target velocity. Sub-optimal method has been proposed using dynamic programming[4,5] and multi-hypothesis-testing approach[6], the cost of reduction of computation complexity undermines the effectiveness of the method. Although the methods mentioned above have become popular, some drawbacks are still in existence, such as the heavy computation burden and more confined to applicable conditions, especially for target speed and movement contrail. So, based on these methods, some fast algorithms[7] and other algorithms, for example, the improved projection detection algorithm[8] and detecting dim point targets with genetic algorithm[9] are developed. However, most of those methods are applicable in the condition that the moving distance of point target is less than a pixel between two frames. How to detect point targets maneuvering acutely in cluster background needs to be studied, that means the moving distance of point target is larger than a pixel more, which fits the trend of super velocity of sound and multiple velocity of sound for modern weapon systems.

In this paper, a novel detection algorithm for moving IR point target is proposed based on the Reverse Phase Feature of Neighborhood (RPFN) of a target in a first order frame difference image. Simulation results indicate that it is a general algorithm with good performance.

1 Feature Analysis of Moving Point Target in IR Image Sequences

1.1 Basic features of IR point target

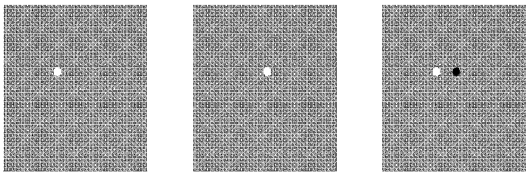
In infrared images a point target exists as only one pixel, thus it is impossible to acquire some basic features such as size, shape, edge, texture, etc, so it is not able to detect it through general image processing methods. Although the gray level of a point target is different from those of neighbors, otherwise it cannot be detected at all, it still cannot be detected only by the gray values because of complex background and all kinds of noise. Besides the gray value of a point target being different from those of their neighbors, the only feature that can be used to detect is its moving feature.

1.2 RPFN of a moving IR point target

The calculation of a first order frame difference image is still an important step for change detection[10, 11]. Also, it is a general way to detect a target in image sequences through background removal by calculating a first order frame difference image or background modeling prediction. However, an effective way for detecting a point target only through a first order frame difference image has not been presented before because there are too many noises in a first order frame difference image, especially for those point targets with low-SNR.

However, through accurately matching background and then calculating a first order frame difference image, the gray values of the two positions of a moving point target in original first order frame difference image are with inverse sign, viz., one of them is positive and the other is negative, and the distance between these two positions is close because the moving distance of a target can be assumed larger than 1 pixel and less than 10 pixels between two frames without interval or with small interval. It can be assumed that the distance is less than 10 pixels in most real conditions. And then there is a pair of neighborhood points with reverse phase in original first order frame difference image. The feature was named as RPFN. With more studies on the feature, it is found that the gray values of the two positions of the point target in original first order frame difference image are not only with inverse sign but also close to in absolute value if the background has no sharp change in a local neighborhood area. Generally speaking, noises can hardly have such feature as RPFN.

The ideal RPFN of a point target in a first order frame difference image is illustrated in Fig.1. It is supposed that there is a bright moving point target in an even gray background. In Fig.1, (a) and (b) are two consecutive frames of an image sequence, and (c) is the difference image between (a) and (b), and of course, a linear transformation from [-255,255] to [0,255] has been made for display. In Fig.1(c), the point target has two positions of which one is bright and the other is dim. Especially the gray values of the two positions are equal in absolute value but with inverse sign in the original difference image. This is the feature of RPFN. Generally speaking, the RPFN reveals an important property of a difference image from two consecutive frames of an image sequence, which indicates that the gray values of the two positions of a moving point target in a first order frame difference image are close to in absolute value but with inverse sign statistically. This is a very simple feature for detecting a point target but it has never been noticed and used before.



(a) (b) (c)

(a) Frame No.1 (b) Frame No.2

(c) Transformed difference image between (a) and (b)

Fig.1 Illustration of RPFN

2 Detection Algorithm of A Moving IR Point Target Based on RPFN

The moving IR point target detection algorithm based on RPFN can be stated as follows.

Algorithm 1:

Step 1 Background image registration

Calculate the moving distances of the background d_x and d_y along the coordinates x and y between two frames by the maximization of correlation.

$$r=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}(F_1(i,j)F_2(i,j))}{\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{m}(F_1(i,j))^2\sum_{i=1}^{n}\sum_{j=1}^{m}(F_2(i,j))^2}} \quad (1)$$

where $F_1(i,j)$ is the gray level function of pixel in a benchmark window in the first frame, $F_1(i,j)\geqslant 0$; $F_2(i,j)$ is the gray level function of pixel in a matching window in the next frame, $F_2(i,j)\geqslant 0$. Obviously, $0\leqslant r\leqslant 1$, and $r=1$ if and only if $F_1(i,j)=F_2(i,j),\ (i=1,2,3,\cdots,n;\ j=1,2,3,\cdots,m)$。

If $F_1(i,j)$ is fixed as a benchmark window in the first frame and as a searching window $F_2(i,j)$ is searching around the corresponding position of the benchmark window in the second frame, the background's moving distances d_x and d_y along the coordinates x and y between them can be found when r is maximized.

In order to reduce the computation time and keep a certain level of precision, four windows of 16×16 pixels instead of the whole image are chosen as benchmark windows in the following method. Then four results can be obtained from four sections. The final result of background registration comes from the four results: if at least three results are the same, then the result is chosen; otherwise re-select the benchmark window and re-calculate. Background registering is a basic and important preprocessing for this algorithm.

Step 2 Calculate the difference image (the area of edge is ignored here)

$$D(i,j)=F_k(i,j)-F_l(i+d_x,j+d_y) \quad (2)$$

where $D(i,j)$ is the original first order frame difference image.

Step 3 Threshold processing adaptively

Threshold T, $T>0$, is selected and the triple-level partition processing can be carried out according to Eq.(3).

$$D_{\text{triple}}(i,j)=\begin{cases}0, & D(i,j)\leqslant -T\\ 127, & -T\leqslant D(i,j)<T\\ 255 & T\leqslant D(i,j)\end{cases} \quad (3)$$

D_{triple} is an image with three levels of pixel gray. Thus, the pixel with gray level 0 or 255 can be found as candidates for the point target, and the pixels with gray level 127 are the background. Obviously, only one phase is chosen as candidate, 0 or 255, and the phase of 0 is chosen here. T is selected adaptively based on α, and that is the percent of target candidates after the processing according to Eq.(3). α should be in an area, and here it is chosen as [0.000 5, 0.001 0] according to the percent of point target in the image. The way to adjust the threshold *T* is based on the following rule: if $\alpha < 0.001$, then increase *T*; else if $\alpha < 0.000\,5$, then decrease *T*.

It should be emphasized that the selection of *T* is important. If the threshold is too small, the purpose of removing noise can not be achieved; otherwise, if it is too large, some targets may be removed. Here a smaller threshold for detection rate is chosen. At the same time, only one threshold *T* is selected, because it is generally assumed that the mean of noise in original first order frame difference is zero.

Step 4 Searching pairs of points with RPFN

Every candidate for the target is examined by RPFN. Searching in a round window that is centered around the candidate for target and with the maximal moving distance of target as radius, if there is not any reverse phrase point in the window, the candidate will be deleted from candidate set. After the examination of all candidates completed, if there is no candidate left，then the value of the threshold *T* is decreased and turn to Step 3. It can not turn to Step 5 until at least one candidate point pair is left there or the number of iterative times is larger than a threshold.

Step 5 Point target detection in a cumulated vectorgraph

Every candidate of point pair can be treated as a vector from the point in the first frame to the point in the second frame. Every vector with five parameters: two coordinates, original gray levels of start point and end point, and the length of the vector. For every first order frame difference image a vectorgraph can be drawn. In a cumulated vectorgraph of three first order frame difference images the point target can be detected by the continuity of the vectors of point pair.

According to the description of the algorithm above, it is clear that only the property of RPNF is used in the algorithm. No prior knowledge—such as speed and type of trajectory of target is required at all. This guarantees the performance of the proposed algorithm for the detection of fast maneuvering point target.

3 Theorem for the Convergence of Detection Algorithm

Firstly, in this section two definitions of the probability of target detection are given separately, and then a theorem for the convergence of detection algorithm is given and proved.

Definition 1: The correct rate of target detection based on images of first order difference is defined as the frequency of correctness of target detections in a whole detection process with first order difference images independently.

Let p is the probability of correct detection for a moving point target in one detection point and q is the probability of target loss in one detection point, including incorrect detection and target losing, then $p = n / N$, where n is the times of correct detections in N detection points, and it is obvious that q=1− p.

In fact, for a moving target, it is more important to find its contrail in a whole detection process than to find itself in some detection points. Even though the target may be lost in a few detection points, it is also satisfied as long as the target contrail can be found. For a detection process with N detection points, the target contrail may consist of N target points if no target loss takes place. Considering the continuity of the target contrail, if the percentage of target loss in some distant isolated detection points is less than a threshold T_{lost}, the detection of its whole contrail can not be affected. Therefore the probability of convergence of target contrail detection process can be defined as follows.

Definition 2: The probability, P_{D}, of convergence of target contrail detection process can be defined as the probability of finding out the target contrail in a detection process with N frames of first order difference image, in which the times of target loss in some distant isolated detection points is less than $T_{\text{lost}}\,N$.

Theorem 1: For the detection of a moving point target in complex background, the target contrail can be found out with P_D approximating to 1 by Algorithm 1.

Proof: According to a real experience various detection points are independent each other in the detection of a moving target, then for a detection process with N detection points the probability, P_D, of finding out the target contrail can be calculated as follows:

$$P_D = C_N^0 q^0 p^N + C_N^1 q\, p^{N-1} + C_N^2 q^2 p^{N-2} + \cdots + C_N^M q^M p^{N-M} \tag{4}$$

where $M = \text{integer}(T_{\text{lost}} N)$. Equivalently, P_D can be calculated by

$$P_D = 1 - (C_N^{M+1} q^{M+1} p^{N-M-1} + C_N^{M+2} q^{M+2} p^{N-M-2} + \cdots + C_N^N q^N p^0) \tag{5}$$

For a certain p, q and a given parameter T_{lost},

$$\lim_{N\to\infty} C_N^{M+i} q^{M+i} P^{N-M-i} = 0 \tag{6}$$

where $i = 1,2,3,\cdots,(N-M)$.

As a consequence, the limit of a sum of definite items can be given as

$$\lim_{N\to\infty} (C_N^{M+1} q^{M+1} P^{N-M-1} + C_N^{M+2} q^{M+2} p^{N-M-2} + \cdots + C_N^N q^N p^0) = 0 \tag{7}$$

and according to Eq. (5),

$$\lim_{N\to\infty} P_D = 1 \tag{8}$$

which gives a very important result that the target contrail can be found out with P_D approximating to 1 by Algorithm 1 and the detection process of target contrail is convergent.

Q.E.D.

This theorem affords a solid guarantee in theory for practical applications of the algorithm proposed in this paper.

4 Results of Simulation Experiments and Validity Analysis

4.1 Simulation images

In order to demonstrate the effectiveness of the novel algorithm proposed in this paper, a series of simulation experiments in various typical complex backgrounds are carried out. In view of their representativenesses, some background images are downloaded from JPL of NASA. Ten typical complex images are chosen as the background images, including cloudy image, forest image, mountainous region image, city image and other complex background images, and they are cropped into 800×700 pixels, as shown in Fig.2.

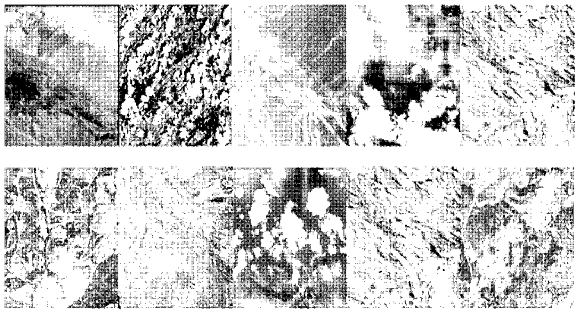
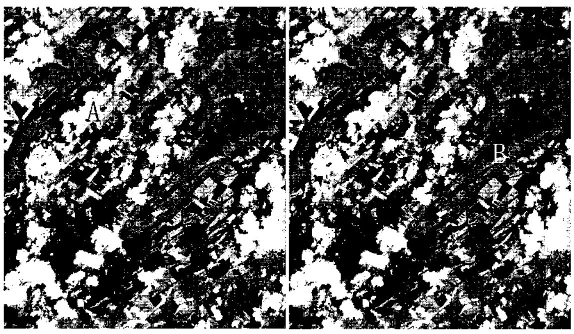


Fig.2 Ten background images used in simulation experiments (800×700 pixels)

For each background image a sequential image with 50 frames are made. Furthermore, the sequential images are made through the following way: first, let the background move with a speed less than 5 pixels per frame. Some noises are added into each frame by Photoshop, then based on these sequential images one moving point target is added to each frame, and only one target is set in one frame here, thus the test image sequences are generated. In these test images, the SNR of point target is about 1.5 to 2, here $\text{SNR} = (s-m)/\sigma$, where s is the average value of target gray level, m and σ are the average value and the standard deviation of background image gray level separately.

Fig.3 shows the simulation target clearly. In



(a) A point target is located at A (b) A point target is located at B

Fig.3 Two frames of simulation sequential images with the target in different contrast conditions

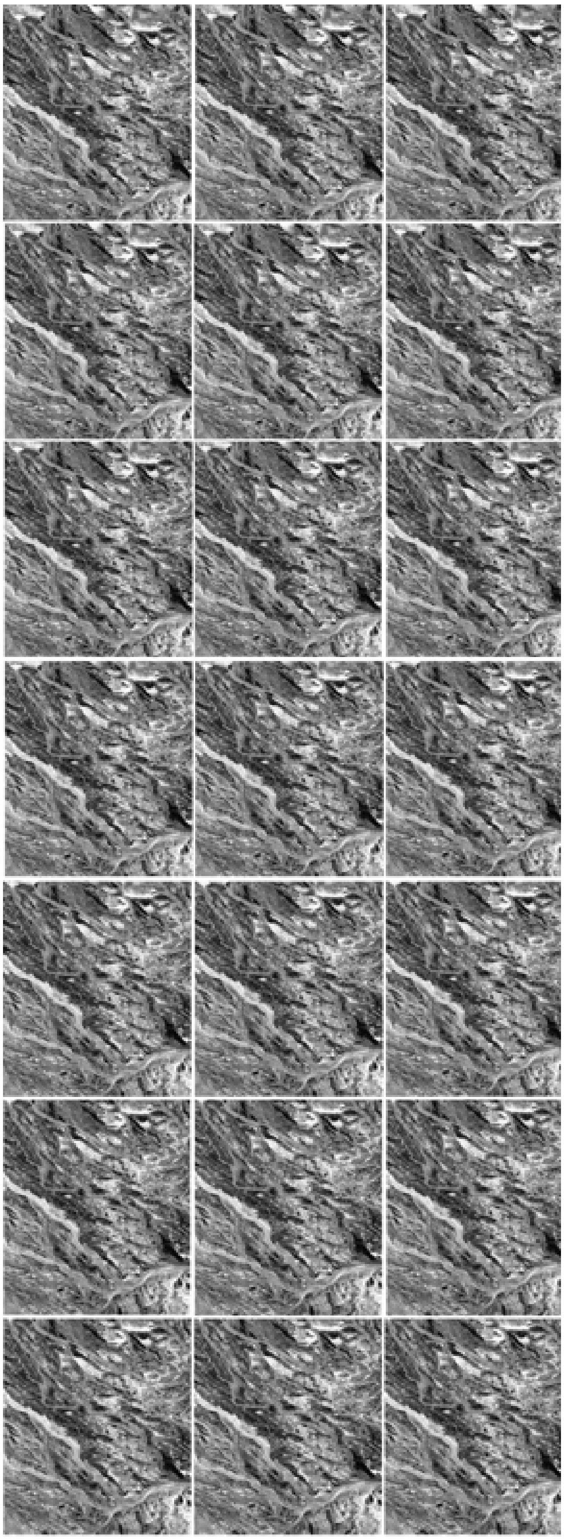
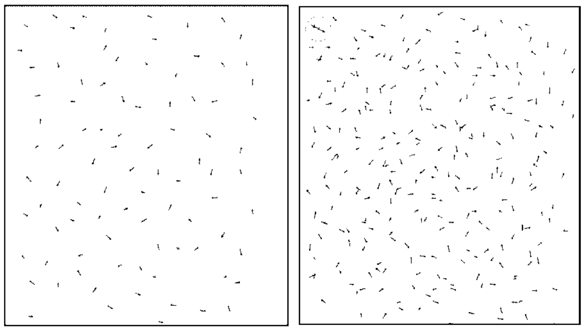


Fig.4　21 frames of a group of sequential images (50 frames) for simulation experiments (SNR =1.5)

Fig.3(a), *A* is the simulation target which is visible in the current contrast condition in the background.
In Fig.3(b), *B* is the simulation target which is dim and invisible in the current contrast condition.

21 frames of a group of sequential images (50 frames) for simulation experiments are shown in Fig. 4, where SNR is 1.5.

Fig.5(a) shows a vectorgraph of point pairs with RPFN. As a result of the test images for SNR=1.5 with low thresholds for high detection rate, many point pairs fitting RPEN form numerous vectors shown as Fig.5(a). In Fig.5(b) a cumulated vectorgraph of point pairs from three frames first order difference images is shown, and a vector locus can be found in the upper left, in which three vectors are connected successionally to form a directional locus as marked by a circle, that means the target has been identified. However, other vectors are in disorder and regarded as noises.



(a) A vectorgraph of point pairs with RPFN　　(b) A cumulated vectorgraph of point pairs

Fig.5　Vectorgraphs according to point pairs with RPFN

The real contrail and fitting contrail of point target in Fig.6 show that a few lost points have little effect upon the detection of the contrail of point targets.

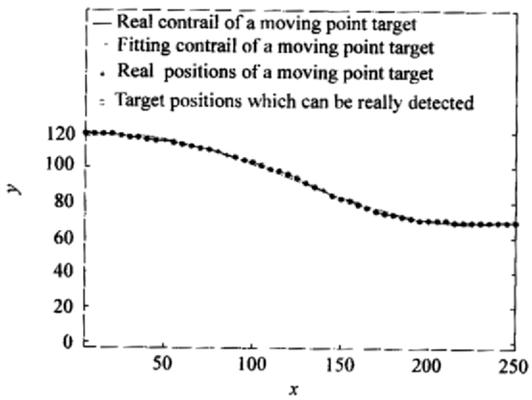


Fig.6　Contrail of a moving point target

4.2 Validity Analysis

(1) Correct rate of detection

A series of experiments have been carried out with 1000 frames of images in 10 kinds of typical complex backgrounds to verify the validity of the detection algorithm proposed in this paper, in which 500 frames with SNR=2 are generated from 10 kinds of different backgrounds, other 300 frames with SNR=1.5 from another 6 kinds of backgrounds in Fig. 2, and the other 200 frames with no simulated target in them as the counterexample. The experimental results are shown in Table 1 and Table 2.

Table 1 Experimental results of the 800 Images with simulated target

Right decision	a =756
Miss	b =44
$P_d \triangleq a/(a+b)$	0.945

Table 2 Experimental results of the 200 Images without simulated target

False hit	c =3
Right decision	d =197
$P_f \triangleq c/(c+d)$	0.015

Out of the 500 frames of background with higher SNR, the experiment results indicate that the target can be accurately detected only within single first order frame difference for 477 frames, thus the validity rate is 95.4%. The reason for losing target lies in the fact that the background changes sharply in a small neighboring area and the contrast relation of the point target with the background is reversed. That means the assumption of the algorithm, which requires steady background within local neighborhood area, can not be satisfied. However, the detection result of next frame can not be affected even though the target is lost in the current frame.

For those 300 frames (SRN is 1.5) the performance of the algorithm falls sharply only with one first order frame difference, but with cumulated vectorgraph the performance becomes more and more better as the cumulated number increases. When the cumulated number is 3, the rate of detection is up to 93%. For those 200 frames without simulated point target as the counterexample, only in 3 frames a false point target is detected incorrectly.

(2) Contrast condition of targets and backgrounds

For half of the simulation images the point target is bright, that means the gray level of target is higher than that of background, and for the other half the contrast condition is reversed yet. However the detection validity is uniform and there is no evidence of different detection results. Therefore there is no requirement of contrast condition of the target to its complex background in the practical application of the detection algorithm in this paper.

(3) Constrain of targets' speed

The moving speed of simulation target is chosen from 1 to 5 pixels per frame. No distinct difference is found for different speeds. Even though the time used for searching the reverse phase point in the neighborhood increases with the moving speed increase because the searching window becomes larger, it is acceptable in practical applications. Generally speaking, this algorithm is applicable to the condition that the moving speed of target is no less than one pixel per frame.

（4） Speed of detection

The test was carried out on a PC with Intel Pentium 4 CPU (1.80 GHz) and 512MB memory. The program is coded with VC++, and the average detection speed is less than 0.1 second per frame. Given the size of simulation image with 800×700 pixels and most of real application images with the level of 300×200 pixels, the speed is fast and there is still some potential space to improve for further applications in real hardware systems.

5 Conclusions

In this paper, a novel algorithm for detecting a moving IR point target in complex background is proposed, which is based on RPFN of a moving point target whose displacement is larger than one pixel between the two frames. The results of simulation experiments show that moving point targets with SNR not lower than 1.5 can be detected effectively. As SNR decreasing again the performance of this algorithm decreases sharply, and then other features are necessary to improve the capability of this algorithm, which is carrying on. By all appearances, this algorithm has its area of application, and in those conditions which background change sharply, such as the glint sea surface background, this algorithm is not applicable because the operation of difference can not complete background removal efficaciously, which is another research area. Although there are some insufficiencies of this algorithm, as a general detection method for a moving point target in complex background it presents a sharp contrast with current tracking ways and pioneers a new approach in this field.

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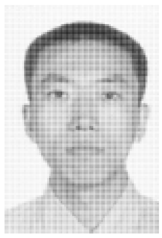

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